# Influence of laser assisted single point incremental forming on the accuracy of shallow sloped parts

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**Abstract.**Inwards bulging of the bottom is a typical geometric inaccuracy in shallow sloped Single Point Incrementally Formed (SPIF) parts. In this work, the effect of applying a localized heated spot moving synchronously with the forming tool on the geometrical accuracy of shallow sloped parts has been studied. To investigate the bulging of the bottom the results of an experimentally validated three-dimensional elasto-plastic finite element modelhave been utilized. These results have been used to identify the contact zone between the tool and the sheet, during Laser Assisted SinglePoint Incremental Forming (LASPIF) process. Moreover, a three-dimensional transient heat transfer model was formulated to identify optimum process parameters for the heating process. FE modeling results have been validated by temperature field measurements obtained from IR camera observations and a good agreement between the experimental data and the model has been observed. Based on the selected process parameters different relative positioning strategies between the tool position and the dynamically heated spot have been selected. Geometrical accuracies and the process forces have been measured and the best forming strategy has been identified accordingly.

**Keywords:**LASPIF; FE modeling; Accuracy; Forming forces; Contact zone

## Introduction

Researchers have been striving to determine a solution to achieve reasonable geometric accuracy in the SPIF process. Therefore, various strategies have been proposed to deal with this concept. Toolpath compensation strategies using feature assisted SPIF (FSPIF) [1], stress-relief annealing of the SPIF part after forming [2], SPIF at elevated temperature [3], FE modeling for geometry prediction and accuracy improvement of SPIF parts [4] and performing statistical methods for predicting the influence of the forming process parameters on the accuracy [5] are some of those techniques. Among different methods which have been developed to deal with the accuracy improvement, LASPIF [3] shows promising potential as an accurate flexible forming process. A localized heated spot, which moves with the tool contact zone in a synchronized way, increases the material ductility around the contact point between forming tool and the sheet. The positive effect of dynamic heating on the accuracy has been confirmed for geometries with high forming angle, which arises from the reduced deflection of the un-stiff robot arm due to the reduced process forces and the reduction in springback of the part. Normally, shallow wall angle geometries show typical geometrical errors such as a bulging of the bottom which cannot be observed in parts which are formed close to their failure angle. This type of geometrical errors influence the forming process by inducing radical forces on the forming tool which results in generation of further geometrical inaccuracies on the SPIF part. Here, a preliminary study has been conducted with the aim to identify the possibility of accuracy enhancement in shallow wall angled geometries using the LASPIF process. Various relative positions of the laser spot in respect to the tool-contact position have been investigated and conclusions have been drawn based on the measured forces and geometric accuracy.

## Experimental setup

AA 5182-O sheet with a thickness of 1.25 mm has been incrementally formed to the shape of a shallow sloped cone (see Figure 1a). In previous research by the author [6] a three-dimensional elasto-plastic finite element model has been developed to investigate the bulging of a cone base during the SPIF process. The FE modeling results revealed that an extended deformation of the sheet outside the tool contact zone is responsible for the typical overforming of the wall and the tool-sheet contact zone is more compact and positioned in the cone bottom region in a shallow sloped part. To compare the effect of laser-tool positioning on the geometric accuracy of the LASPIF process a circular laser spot with a top-hat profile, which is produced from an Nd-YAG (1.06 μm) laser source, has been positioned in three different regions with respect to the forming tool, no forward offset in the direction of the tool movement has been applied between the centers of the laser spot and the tool stylus(see Figure 1). Using thermal FE modeling optimum laser process parameters for LASPIF process have been selected and validated by IR camera measurements. A 3-axis force measurement platform and 3D coordinate measurement machine equipped with a laser line scanner have been used to measure process forces and geometric accuracy of LASPIF formed parts. Those results are compared with the cold SPIF process results for all three different positing conditions and finally the best forming strategy has been identified.

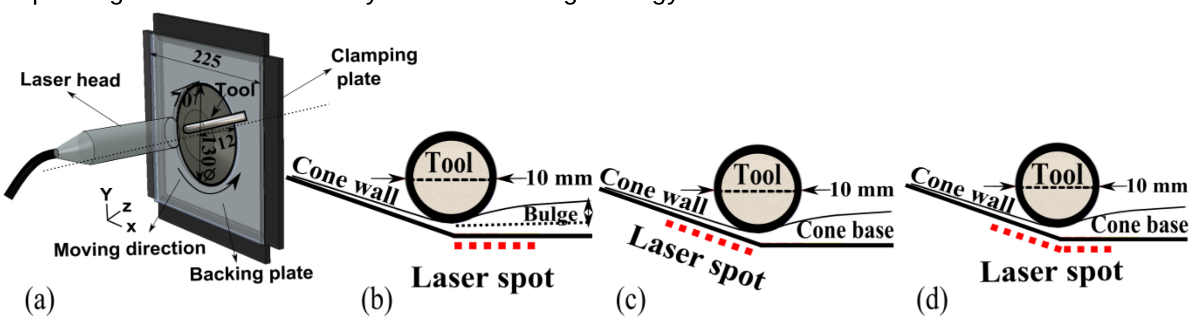


**FIGURE 1.** a) Schematic representation of a LASPIF process and truncated cone dimensions, b) 5mm inside offset, c) 5mm outside offset and d) No offset between the laser and the forming tool. The process parameters: a tool diameter and laser spot size of 10 mm, forming and laser scanning speed of 1000 mm/min and the stepdown of 0.75 mm in Z direction.

## Numerical description of the thermal model

A 3D transient heat transfer model has been formulated to identify a set of optimum process parameters for the heating process on the flat sheet surface. Half of the sheet has been modeled and meshed using an 8-node linear heat transfer hexahedron. The laser beam is simulated as a heat flux that changes its place in small time increments along the scanning path. Each area segment of the sheet is under influence of the heat load for a time step equal to the laser-sheet interaction time which is determined by the scanning velocity (see Figure 2a). Temperature dependent thermal properties of this alloy are selected from the reference [7]. In this model heat losses due to radiation and natural convection are considered while the heat conduction to the backing plate and clamping plates is neglected. The emissivity(ε) of the material has been calculated using an IR camera and thermocouples to verify the true temperature. An optimum laser power and scanning speed have been obtained for a 10 mm laser spot size in a way that a circular heated region of 10 mm diameter on a sheet perpendicular to the laser beam exceeds 270°C (see Figure 2b). This temperature is considered as an optimum warm forming temperature of AA5182 alloys [7].Results of the infrared thermography measurement of the sheet are presented in Figure 2 c.During LASPIF tests, for the cases indicated in Figure 1 c and d the circular laser beam or the part of it has been irradiated to the inclined surface (i.e. cone wall) this results in the reduction of heat flux compared to the case where the laser beam is radiated on a surface perpendicular to the laser beam. However, for the studied shallow sloped part because of the small forming angle, the increase in the laser spot area and the reduction in the heat flux is 6% which has been neglected in the thermal modeling.

## Results and discussion:

Figure 2 b and c show the measured and simulated size of the 270 ºC isotherm, it has been confirmed that if the sheet metal is scanned with a laser power of 300W, scanning speed of 1000 mm/min and the laser spot diameter of 10 mm, the forming process will be performed at temperature equal or greater than 270 ºC. Figure 2 d shows a comparison of temperatures at the selected node indicated by an arrow in Figure 2b and c, a maximum temperature of 315°C is achieved at the tool side surface of the sheet, meanwhile the maximum predicted surface temperature at the laser side doesn't exceed 328ºC which is well below the sheet melting point, 577ºC. The simulation and experimental results show good agreement, both in isotherm size and the maximum achievable temperature. These process parameters have been used for LASPIF process.

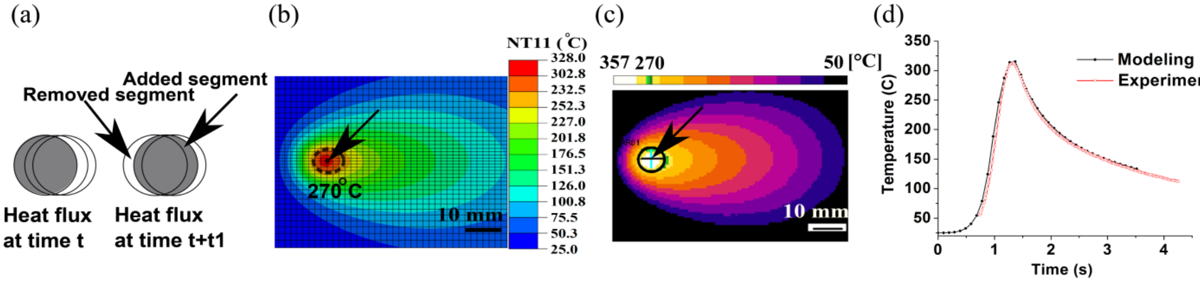


**FIGURE 2.** a) Schematic illustration of the laser movement, b) Thermogram of the sample during the laser scanning measured by IR camera ($\varepsilon_{270^{\circ}C}$ = 0.968), c) Temperature contours at the tool side of the sheet surface calculated by FE modeling and d) Comparison between measured and predicted thermal cycles at the peak temperature specified by arrows.

(Note: The surface temperature of the material is measured and calculated at the tool side of the sheet,3.5 s after the start of the laser scanning.)

Comparison of accuracy results with the cold SPIF case show a reduction of 42.3% in the bulge height for the outside offset case. However, for the cases of without and inside offset, the bulge height increases about 9.79 % and 27.3 % respectively (see figure 3). Moreover, it has been observed that the overforming of the cone wall formed in cold SPIF changes to an underforming in the LASPIF process. It is believed that this deformation is caused by thermal stresses induced during laser scanning. Due to the high thermal conductivity of the Aluminum sheet, slow scanning speed and a big spot size no significant thermal gradient occurs through the sheet thickness and differential thermal expansion will be prevented accordingly [8]. Therefore, an observed bending of the sheet towards the laser beam (concave curvature) cannot be attributed to the temperature gradient mechanism. However, since the size of the laser spot is more than 5 times bigger than the sheet thickness and along thickness temperature gradient is limited, development of thermo-elasto-plastic buckling of the sheet is expectable. In this case the bending angle direction is toward the laser beam which might be due to the nature of pre-existing residual stresses from the cold-working and internal stresses developed during the SPIF process resulting in the largest underforming for the case with outside offset where the laser beam irradiated to entirely deformed regions of the sheet. An underforming of the cone wall might be controlled by using a smaller spot size which reduces concave buckling of the sheet but to assure correct laser-tool positioning the higher robot stiffness is required. A more optimal strategy for prediction of possible laser forming mechanisms during LASPIF process by using a sequentially coupled heat transfer analysis, in which obtained temperature results is read into the stress model as a predefined filed is a subject for the future work.

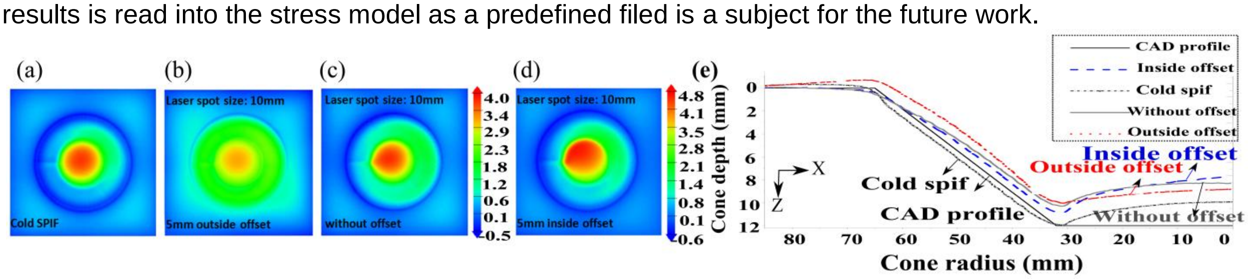


**FIGURE 3.** Influence of the laser positioning on the measured geometric accuracy a) cold SPIF, b) 5 mm outside offset, c) no lateral offset, d) 5 mm inside offset and e) accuracy comparison at the cross section parallel to X axis.

For better understanding of the LASPIF process, forming forces are recorded during the sheet metal forming (see Figure 4). From Fx and Fy force components it can be concluded that the radial component

Fr is negative for all cases which means that the tool has been pushed outward for all three strategies and the inner part of the bulge induces a higher radial reaction forces in the outward direction. However the magnitude of Fr has been significantly reduced in the outward offset case as result of the diminished bulging. It is believed that formation of a ductile zone at the cone wall region is responsible for less bulging of the bottom which results in changing the position of contact zone from the bulged bottom towards the wall. Furthermore, in an outward offset case due to the reduction in the forming forces the deflection of the robot arm, used to move the tool, decreases resulting in formation of the part with higher overall accuracy. Applying the laser at the cone base causes an increase in the bulge height and generation of the bulge at the last forming steps pushes the tool backward towards the robot side (see Figure 4c).

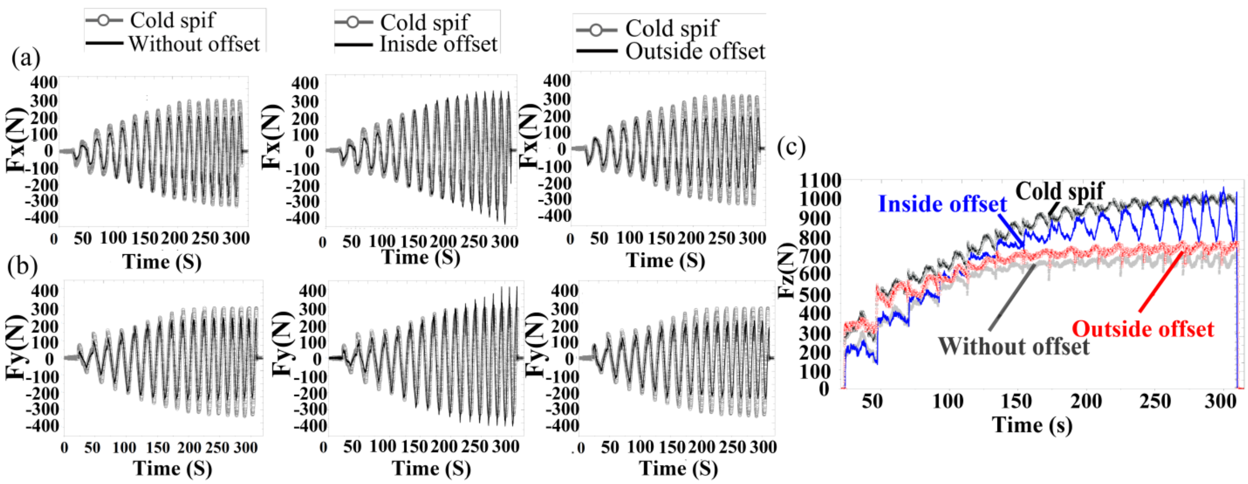


**FIGURE 4.** a) Fx, b) Fy and c) Fz versus time for three different tool-sheet positioning conditions.

## Conclusion:

Thermal FE modeling has been successfully used to predict optimum process parameters for forming AA5182-O at elevated temperatures. Three different LASPIF strategies have been applied to study the influence of the laser tool positioning on the accuracy of the SPIF parts. Using geometrical accuracy and force measurement results it has been concluded that a 5mm outside offset between the laser and the center of the forming tool shows 42% decrease on the bulge height compare to the cold SPIF process. Moreover, reduction in forming forces results in generation of more uniform part due to increasing the dynamic stiffness of the robot.

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